Centroidal Momentum analysis for defining a stability index for human-exoskeleton interactive walking : Perturbation detection in human gait

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Recently, exoskeletons have been in the spotlight as many studies demonstrated the effectiveness of the exoskeletons as a means that enables to not only resolve long-standing issues such as increase of societal burden for the care of ageing populations but also augments productivity in several fields, such as rehabilitation and industrial fields. In particular, lower limb exoskeletons have attracted the medical field, especially related to the ageing society due to its impact on augmentation and recovery of walking capability which is one of the core determinants of independent daily living [1]. For practical use of the lower limb exoskeletons in real environments, however, there are still several issues to be resolved. One of them is how to manage balance of human walking supported by the exoskeleton, in other words, how to monitor walking stability of a system combined with human and exoskeleton and maintain (or recover) the system balance when the user meets unpredicted disturbances, and thus to avoid falls.

The former is a rationale of the study and this paper deals with a 'stability index', referred to as a kind of measure to monitor the actual (in)stability state during walking. The proposed stability index is based on the Centroidal Momentum (CM) that consists of linear and angular momenta at the Center of Mass (CoM). CM is a fundamental parameter used to describe physical motion of a system in classical mechanics, and it has been studied widely in biomechanics and bipedal robot fields over the last decade [2] as it, specifically angular momentum-based analysis, offers important clues on how humans maintain balance during walking [3] as well as facilitates postural balance control of humanoid robots in standing [4].

As an extension of this context, in our previous work [5], we analyzed CM behavior during human walking under perturbations, specifically lateral perturbations applied to the pelvis. As a continuation of the study, in this paper, we examine whether CM could be used as the stability index to detect the perturbations as well as an initial loss of balance, in other words, a perturbation detection method on the basis of calculation of Centroidal Momentum (CM) in human waking is presented. In the method, variation of CM patterns between unperturbed and perturbed walking plays a crucial role in detecting perturbations. The method has been evaluated with experimental data of human walking and results show that the method is capable of detecting moderate and strong perturbations determined by combination of diverse durations and magnitudes of disturbance force. Average detection time was about 334 msec.

This study was carried out in the context of the EU FP7 project BALANCE that aims at supporting the function of maintaining postural balance directly through a leg exoskeleton. For this purpose CM-based stability index to be developed will be extended to the exoskeleton cooperating with a human and assessed on performance in this context.

This study has been supported by EU funded project BALANCE, FP7-ICT-2011.2.1 grant no. 601003.

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